NAVAL POSTGRADUATE SCHOOL
Monterey, California

ECE 3210 **LENS SYSTEM PARAMETERS** 10/98 Po

Objective: In this experiment we will measure and become familiar with lenses and the application of such parameters as focal length, field of view, depth of focus, f-number, etc.

Equipment:

- HeNe laser ($\lambda = 632.8$ nm)
- Lenses
  - 10x microscope objective ($f = 16$ mm)
  - 50 mm TV lens
  - 2 inch diameter lens ($f = 10$ inches)
  - unknown focal length (called "lens #2")
- Iris diaphragm (adjustable aperture)
- Optical bench
- Closed circuit TV (CCTV) system
- TV lenses
  - 50 mm focal length
  - 12.5 mm focal length
- Measuring tape, meter stick
- "Goose neck" desk lamp
- "Punch-out" card object

Reference: An excellent practical description of lens systems is found in *Infrared Systems Engineering* by R.W. Hudson (J. Wiley & Sons, 1968).

Procedure:

1. Collimator: An *optical collimator* (or *beam expander* is an arrangement of lenses designed to produce a beam of low divergence. The simplest collimator is two lenses arranged as shown in Fig. 1 on the following page. The relations between the various dimensions are:

$$\frac{\theta_2}{\theta_1} = \frac{d_1}{d_2} = \frac{f_1}{f_2}, \tag{1}$$

where θ is the beam divergence, d is the beam diameter, and f is the focal length of the lens. (Why is this device also called a "beam expander"?) This lens arrangement is also found in a telescope.

Using the lenses supplied (the 16 mm microscope objective and the 10" focal length lens), construct a beam collimator. Experimentally check the collimation by observing the that the diameter of the collimated beam does not change. Correct the lens spacing if necessary. Check the focal length of the 10" focal length lens by calculating the value from the distance measured between the lenses.

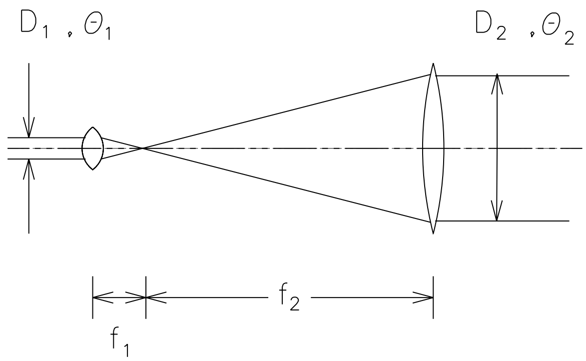

Figure 1: Beam collimator

2. Focal length: A lens or lens system will focus a collimated beam at its focal length. The distance is measured from the intersection of the continuation of the input beam with the backward continuation of the focused beam as shown in Fig. 2 on the next page.

   The value of f can be calculated from a measurement of the input beam diameter and the full angle of the cone apex. Using the geometry of Fig. 3 on page 4, devise a procedure for measuring the focal length of the lens system in the figure (i.e., write a formula that gives f in terms of D_1, D_2, and x).

   > *Using your collimated laser beam, measure the focal length of lens #2 and the 50 mm TV lens. (Be sure that the 50 mm lens is focused at ∞ and that the aperture is fully opened.)*

3. Images: Lenses can be used to image objects (Fig. 4 on page 4). The relation between the object distance o, the image distance i, and the focal length f is given by the lens formula:

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}\,. \tag{2}$$

   The ratio of the size of the image to the size of the object (i.e., the magnification or demagnification) is given by:

$$M = \frac{i}{o}\,. \tag{3}$$

   > *Using the "goose–neck" desk lamp as a source, the punch-out card as the object and lens #2 as the imaging lens, verify Eqs. 2 and 3. 3. Carefully describe your procedure and results.*

4. Depth of focus: The "depth of focus" of a lens is the longitudinal distance over which a fixed object is said to be "in focus". Theory gives this distance as

$$d = 4\lambda(\mathrm{f/no.})^2\,, \tag{4}$$

   where λ is the nominal wavelength of the illumination (assume 500 nm for white light), and f/no. is the "f-number" of the lens as given by

$$\mathrm{f/no.} = \frac{f}{D}\,. \tag{5}$$

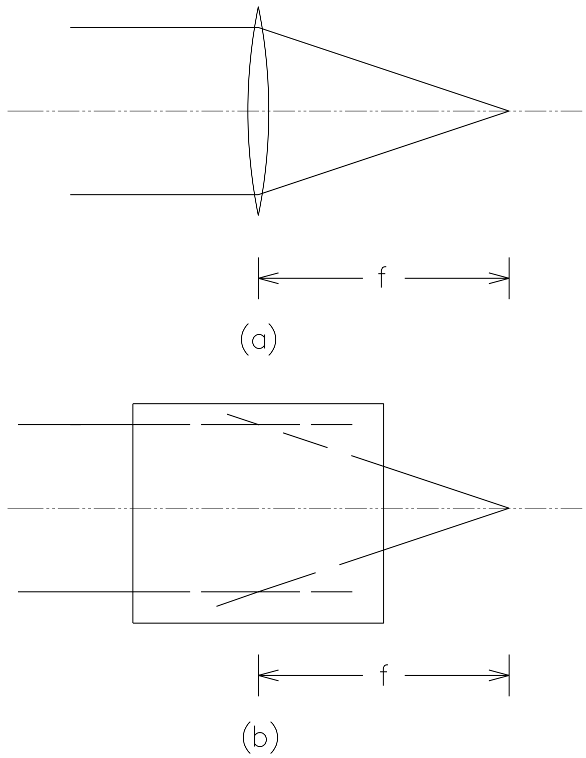

Figure 2: a) Focal length of simple lens, b) focal length of compound lens.

Here f is the focal length of the lens and D is size of the input aperture of the lens (which can frequently be changed by an iris diaphragm called an "aperture stop" in the lens.

> *Calculate the depth of focus for the 55mm TV lens with the aperture fully open. Verify your calculation by measurement if possible.*

5. Depth of field: Another lens parameter of interest is the "depth of field"–the longitudinal distance that an object can be moved without its image coming out of focus (a subjective judgment by the observer). Each TV lens has a depth of field scale inscribed on it showing the depth of field as a function of object distance and f/no.

   Using the CCTV and the 50 mm TV lens measure and plot the depth of field as a function of f/no. (Before measuring the depth of field, be sure to set the focus of the lens to the minimum focus – i.e., set the focus for the object being at its closest position.)

   Repeat with the 12.5 mm lens, plotting your data on the same graph.

   - *Based on your measurements, does the depth of field increase or decrease as the aperture becomes smaller?*
   - *For a set aperture, does the depth of field increase or decrease as the focal length of the lens becomes longer?*

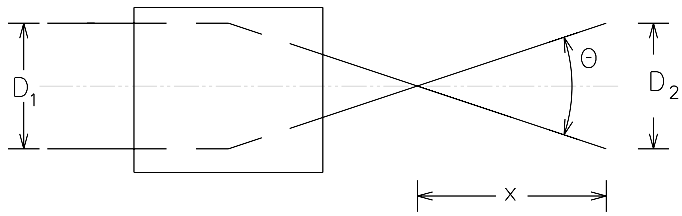

Figure 3: Geometry of a lens focusing a collimated beam

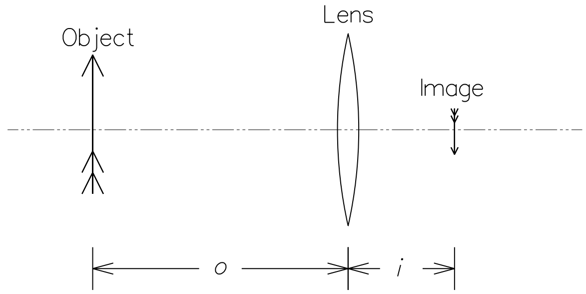

Figure 4: Imaging geometry.

6. Field of view: Another parameter of interest is the "field of view" (FOV) of a lens (i.e., the angular measure of the space within which the system can image the target). This parameter depends on the optical elements, the detector size and the location of "stops" or baffles within the lens system (called "field stops").

   Using the CCTV and the 50 mm TV lens measure the FOV (half cone angle) for various f/no. (Before measuring the FOV, be sure to set the focus of the lens to the minimum focus – i.e., set the focus for the object being at its closest position.)

   Does FOV depend on the f/no for this lens?

   Repeat for the 12.5 mm lens. Does FOV increase or decrease with increasing focal length?

Report: Each group should record the laboratory results on paper. A finished report, together with the plotted data, is due within one week after the completion of the laboratory exercise.